# 4. Cost and Emission Reduction Analysis of $SF_6$ Emissions from Magnesium Production and Parts Casting in the United States

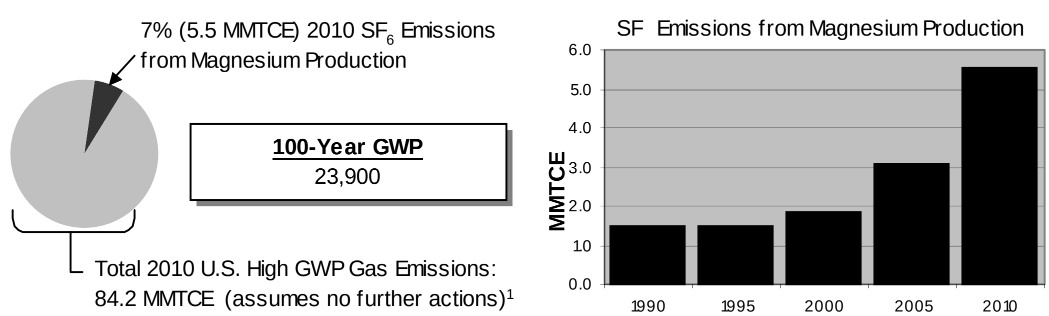
## 4.1 Introduction

The magnesium metal production and casting industry uses sulfur hexafluoride ($SF_6$) as a cover gas to prevent the violent oxidation of molten magnesium in the presence of air. $SF_6$ is a colorless, odorless, non-toxic, and non-flammable gas with a GWP that is 23,900 times that of carbon dioxide over a 100-year time horizon and an atmospheric lifetime of 3,200 years (EPA, 2000). Under a business-as-usual scenario, by 2010 the United States could emit 5.5 million metric tons of carbon equivalent (MMTCE) $SF_6$ from magnesium production and processing (see Exhibit 4.1).[1] However, as noted below, actual emissions are expected to be lower as a result of voluntary industry actions.

Small concentrations of $SF_6$ in combination with carbon dioxide and/or dry air are blown over molten magnesium metal to induce the formation of a protective crust. The industry adopted the use of $SF_6$ to replace sulfur dioxide ($SO_2$), which is toxic and requires careful handling, to protect worker safety. The $SF_6$ technique is used by both producers of primary magnesium metal and by most magnesium part casters. Historically, more than half of $SF_6$ emissions from the U.S. magnesium industry have come from primary magnesium production. However, because of production facility closures and continued growth in the magnesium casting sector, primary production emissions currently account for less than 50 percent. The magnesium recycling industry, for the most part, continues to employ sulfur dioxide as a covergas.

In 1999, EPA began the voluntary $SF_6$ Emission Reduction Partnership for the Magnesium Industry. Individual magnesium producer or casting company partners signed a memorandum of understanding (MOU) with EPA committing to report their emissions of $SF_6$ annually and to take cost-effective actions to reduce those emissions. EPA works together with its industry partners to review and evaluate

**Exhibit 4.1: U.S. Historical and Baseline $SF_6$ Emissions from Magnesium Production**




[1] An explanation of the business-as-usual scenario under which baseline emissions are estimated appears in the Introduction to the Report.

emission reduction strategies and technologies, promote technical information sharing by preparing annual reports and hosting technical conferences, record and verify the partners' progress, and provide positive public recognition for the partners' achievements.

## 4.2 Historical and Baseline $SF_6$ Emission Estimates

Exhibit 4.2 presents historical $SF_6$ emissions from magnesium production and processing (EPA, 2001).

**Exhibit 4.2: Historical $SF_6$ Emissions from the Magnesium Industry (1990-1999)**

| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Emissions (MMTCE)** | 1.5 | 1.5 | 1.5 | 1.5 | 1.4 | 1.5 | 1.5 | 2.0 | 1.7 | 1.7 |
| **Emissions (metric tons)** | 230 | 230 | 230 | 226 | 213 | 230 | 234 | 314 | 264 | 255 |

Source: EPA, 2001.
Note: Conversion to MMTCE is based on the GWPs listed in the Introduction to the Report.

Baseline emission estimates for 2000, 2005, and 2010 are presented in Exhibit 4.3. These estimates do not include reductions anticipated under the $SF_6$ Emission Reduction Partnership for the Magnesium Industry.

**Exhibit 4.3: Baseline $SF_6$ Emissions from the Magnesium Industry (2000–2010)**

| Year | 2000 | 2005 | 2010 |
|---|---|---|---|
| **Emissions (MMTCE)** | 1.8 | 3.1 | 5.5 |
| **Emissions (metric tons)** | 283 | 474 | 850 |

Note:
Forecast emissions are based on a business-as-usual scenario, assuming no further action.
Conversion to MMTCE is based on the GWPs listed in the Introduction to the Report.

## 4.3 $SF_6$ Emission Reduction Opportunities

The most promising options to reduce $SF_6$ emissions from magnesium production and processing can be grouped into the six categories listed below.

### *Good Housekeeping*

The measures referred to as "good housekeeping" result in more efficient use of SF6 in magnesium production and processing and are currently implemented at some facilities. Examples of good housekeeping include:

- Daily $SF_6$ leak detection and maintenance, including:

  ➤Checks of the crucible's lid tightness, $SF_6$ flow meter, and flow meter settings.

  ➤Inspection and record keeping of $SF_6$ line leaks and flow rates.

- Monthly $SF_6$ leak detection and maintenance, including:

  ➤Extensive maintenance checks for $SF_6$ leakage.

  ➤$SF_6$ flow meter calibration.

- Installation of centralized covergas mixers and semi-annual calibration of existing covergas mixers (following guidelines for $SF_6$/$CO_2$/air mixtures to minimize $SF_6$ concentrations).

- Actions to minimize $SF_6$ gas buoyancy (minimize temperature of furnace, use external manifolds to supply gas at coolest possible temperature, feed gas at high velocity).

- Assuring cover gas quality (e.g., minimizing moisture if ambient air is used).

If good housekeeping measures were thoroughly implemented throughout the U.S. magnesium industry, EPA estimates that emission reductions could be on the order of 30 percent. This reduction potential is based on expert opinion and the effectiveness of directed inspection and maintenance in similar emission reduction programs, such as those reported by industry partners in the Natural Gas STAR Program, an EPA-industry partnership that promotes cost-effective reductions in methane emissions.

### *Process Optimization*

The practices referred to as "process optimization" also result in the more efficient use of $SF_6$ in magnesium production and processing. These measures are incremental to "good housekeeping" and represent the latest developments in technology and management practices. Some process optimization measures have not yet been implemented at any facility. There are currently no emission reduction or cost data available for these measures. Examples of process optimization include:

- Installation of cooling pipes along magnesium ingot casting machines (applicable to metal production only). Cooling pipes reduce the amount of time that magnesium is in a molten state, and therefore reduce the amount of time during which a covergas like $SF_6$ is needed;
- Upgrade of magnesium ingot loading doors in re-melt furnaces at processing facilities to minimize fugitive emissions of $SF_6$ (e.g., doors with air lock systems);
- Installation of switches to increase (decrease) flow rate when the loading door opens (closes) rather than a constant high flow rate system; and
- Reconfiguration of cover gas distribution system outlets to optimize $SF_6$ use.

### *Capture/Recycle $SF_6$*

Air Liquide developed an $SF_6$ capture/recycle system that could reduce $SF_6$ emissions by up to 95 percent from current levels (Li, 2000). This patented process uses semi-permeable hollow membrane fibers to separate $SF_6$ from $CO_2$ and air in the spent cover gas. The captured $SF_6$ can be re-used by the industry on-site. The recovery cost—ranging from \$3.60 to \$8.00 per pound of captured $SF_6$—would be cheaper than current market prices for virgin $SF_6$. Air Liquide plans to market the system on a service contract basis covering installation, start-up, and maintenance for a monthly fee.

### *Replace $SF_6$ with $SO_2$*

$SF_6$ was introduced to replace $SO_2$, as the latter is toxic and has a low threshold (2 PPM) for workplace exposure. $SO_2$ usage also corrodes casting equipment. However, safer $SO_2$ handling procedures and the relatively low cost of $SO_2$ as compared to $SF_6$ makes $SO_2$ more attractive. $SO_2$ replacement could potentially eliminate a large portion of $SF_6$ emissions from the magnesium industry, but there are substantial costs associated with switching to $SO_2$ in terms of increased capital cost for metering and distribution, gas scrubbing, and corrosion protection in surrounding structures. $SO_2$ is subject to other forms of air and safety regulation and it is also a major cause of acid precipitation.

### *Replace $SF_6$ with HFC-134a*

Preliminary laboratory trials by CSIRO, Australia have shown that the gas 1,1,1,2-tetrafluoroethane ($C_2H_2F_4$) or HFC-134a (largely used as a refrigerant gas to replace the CFC refrigerant R-12) provides excellent protection of molten magnesium. At one-third the cost of $SF_6$, HFC-134a has no ozone depleting potential (ODP) and a GWP of 1,300, which is substantially lower than the 23,900 GWP for $SF_6$.

The disadvantage with HFC-134a is that the elevated temperature of the magnesium melt will cause some decomposition of HFC-134a into HF gas and other components. HF gas may affect operator safety and accelerate corrosion of equipment (Cashion *et al*., 2000). Nevertheless, substituting HFC-134a for $SF_6$ is a promising alternative.

### *The Magshield® System*

The Magshield® system was developed by HATCH and tested at Lunt Manufacturing Company. The system produces $BF_3$, a protective gas liberated through the decomposition of a solid fluoroborate in a furnace. Gas is thus generated only when required. $BF_3$ is not a greenhouse gas and prospects of a major spill of the fluoroborate are virtually non-existent as the fluoroborate exists in solid form. $BF_3$-generating costs are significantly lower than $SF_6$ and $BF_3$ is easier to scrub with water. The amount of waste sludge generated may also be less than $SF_6$ (Revankar *et al*., 2000).

### *Thixomolding® (applicable to casting only)*

Thixomolding® is a process invented and sold by Thixomat for the high speed molding for metal parts that does not involve molten magnesium and therefore eliminates the need of a covergas like $SF_6$. During Thixomolding®, high-speed mixing heats magnesium metal granules into a semi-solid phase. This semi-solid material is then injected into a mold. Thixomolding® is marketed primarily to companies that manufacture plastic molding and it is mostly popular with manufacturers of small consumer electronics in Asia. As Thixomat is not focusing on marketing Thixomolding® as an alternative to conventional magnesium casting, Thixomolding® is not expected to diminish conventional diecasting or $SF_6$ use in the United States in the foreseeable future (Lebean, 1999).

## 4.4 Cost Analysis

This analysis considers $SF_6$ emission reductions for four incremental possibilities that collectively could reduce emissions by 99 percent. The reduction possibilities summarized below include $SO_2$ replacement, good housekeeping, and Air Liquide's capture/recycle technology. HFC-134a replacement was not included in the cost as research on HFC-134a for this purpose is still in its early stages. Further research on optimum concentrations and flow rates for industrial usage of HFC-134a is needed in order to identify costs (Cashion *et al*., 2000). Given current market conditions, there are also no plans to market Magshield® on an industry-wide level (Schultz, 2001).

Exhibit 4.4 summarizes the potential emission reductions and associated costs of $SF_6$ reduction per TCE.

### *Replace $SF_6$ with $SO_2$*

Capital costs for replacing $SF_6$ with $SO_2$ in 2000 are estimated to be $15.887 million. This includes retrofitting expenses as well as the purchase of $SO_2$-compatible equipment (CHEMinfo, 1998). A one-time $310,927 start-up cost for a worker safety training program for all firms is also included in the capital costs. For this analysis, EPA assumed that 60 percent of $SF_6$ emissions could be reduced by $SO_2$ replacement in 2010 at a cost of $0.25 or $0.24 per TCE depending on the discount rate applied.

### *Good Housekeeping*

Good housekeeping results in more efficient $SF_6$ use. There are no capital costs associated with good housekeeping. Annual O&M savings estimates for the whole industry are based upon estimated leakage rates. Firms not implementing the $SO_2$ replacement technology could opt for good housekeeping and this could reduce $SF_6$ emissions by a further 0.7 MMTCE or 12 percent of 2010 baseline emissions at savings of $1.91 per TCE.

### *Capture/Recycle $SF_6$*

Since this technology is offered on a service contract basis, investment is therefore limited to the cost of collecting and conducting the spent gas to the preferred system location in the plant. This is a minimal one-time cost borne by the client. A capital cost of $100,000 was assumed for the cost analysis. The size of the system, and thus its associated monthly fee, will vary depending upon volume of treated gas, concentration of $SF_6$ in the exhaust line, and target concentration of $SF_6$ required for re-injection as feed gas. The cost per pound of recovered $SF_6$ (including electric power used to operate the system) was estimated at $7 (Li, 2000). In view of the modular nature of the system, the cost per pound of recovered $SF_6$ will probably vary little with total treated volume. Similarly, for the same treated volume and initial concentration, a higher required final concentration results in a marginally higher unit recovery cost. However, for the same target conditions, a lower initial concentration can increase unit recovery cost significantly. In the worst case, the cost per pound of $SF_6$ recovered should still be cheaper than the current price of purchased gas and therefore, O&M savings were conservatively assumed to be identical to good housekeeping. The cost analysis shows that the capture and recycling of $SF_6$ could reduce 1.5 MMTCE or 27 percent of baseline emissions at savings of $0.90 or $0.89 per TCE, depending on the discount rate.

| Exhibit 4.4: Emission Reductions and Cost in 2010 | | | | | | |
|---|---|---|---|---|---|---|
| Option | Break-even Cost ($/TCE) Discount Rate | | Incremental Reductions | | Sum of Reductions | |
| | 4% | 8% | MMTCE | Percent | MMTCE | Percent |
| Good Housekeeping | (1.91) | (1.91) | 0.7 | 12% | 0.7 | 12% |
| $SF_6$ Capture/Recycle | (0.90) | (0.89) | 1.5 | 27% | 2.2 | 39% |
| $SO_2$ Replacement | 0.25 | 0.24 | 3.3 | 60% | 5.5 | 99% |

Notes:
2010 baseline $SF_6$ emissions from the magnesium industry equal 5.5 MMTCE.
Conversion to MMTCE is based on the GWPs listed in the Introduction to the Report.
Values in parenthesis indicate savings.
Sums might not add to total due to rounding.

## 4.5 References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